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Published in:

Proceedings of the 6th Conference on Industrial Computed Tomography (iCT 2016)

Publication date:

2016

Document Version

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):

Stolfi, A., & De Chiffre, L. (2016). Selection of items for “InteraqCT Comparison on Assemblies”. In *Proceedings of the 6th Conference on Industrial Computed Tomography (iCT 2016)*
<http://www.ndt.net/search/docs.php3?showForm=off&id=18776>

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Selection of items for “InteraqCT Comparison on Assemblies”

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Abstract

A new interlaboratory comparison concerning dimensional measurements from CT scans on assemblies is coordinated by DTU as an activity under the InteraqCT Marie Curie project. The paper discusses the selection of comparison items. The first assembly is a reference object produced at DTU, comprising an aluminium step gauge embedded inside a glass tube. The item is distributed to participants who are offered to carry out dimensional measurements at two different levels: 1) as instructed by coordinator; 2) at participant’s own choice. The second assembly is based on an industrial assembly, provided by Novo Nordisk A/S, encompassing two different polymer materials. This item consists of a data set for electronical distribution to participants who are offered to carry out dimensional measurements at two different levels: 1) high noise data set and 2) low noise data set.

Keywords: interlaboratory comparison, Computed Tomography, assemblies, metrology, InteraqCT

1 Introduction

The InteraqCT interlaboratory comparison on assemblies is a new activity organised by the Centre for Geometrical Metrology (CGM), Department of Mechanical Engineering, Technical University of Denmark (DTU) and carried out within the Marie Curie ESR Project INTERAQCT - International Network for the Training of Early stage Researchers on Advanced Quality control by Computed Tomography [1]. The purpose of the comparison is to investigate the performance of industrial Computed Tomography (CT) with respect to dimensional measurements on assemblies. The comparison has been designed to a) test applicability of CT for measurement on assemblies with features as well as materials commonly used in industry, b) evaluate the impact of the operator over the whole CT workflow, c) evaluate the impact of post-processing settings (such as noise reduction, BHC, volume segmentation, etc.) on the accuracy of CT measurements, d) collect and share knowledge on practical aspects related to the traceability of measurements using industrial CT, and e) support the development of CT metrology user community. In contrast to earlier comparisons [2-3], the InteraqCT comparison extends beyond the edge of physical items by introducing a voxel item. The voxel item is basically an item scanned by coordinator and electronically distributed to participants. The introduction of such an item brings the following advantages:

- it enables to determine whether CT-post-processing poses a problem for the accuracy of CT measurements isolating CT-post-processing from the whole CT measurements workflow.
- it allows to conduct a parallel circulation, based on the same item.
- It does not require physical circulation, by eliminating issues associated with the long-term stability;
- It gives significant cost savings associated with manufacturing, calibration and shipping.

The 1-year time scheduling of the project is schematically described in Figure 1. The physical and electronical circulation of the items is ongoing, based on a parallel distribution. A number of 22 participants are involved in the project, some of which for the first time.

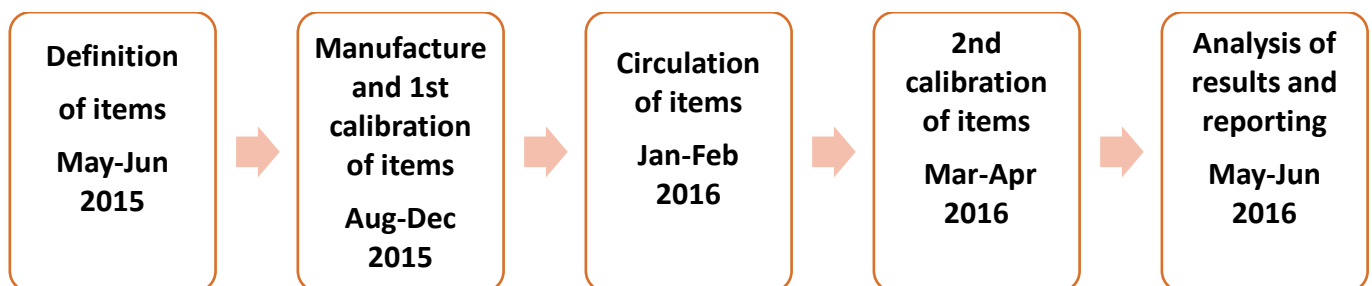


Figure 1. Time schedule for the comparison encompassing the different tasks.

1 Audit assemblies

A successful comparison is definitely based on an accurate selection of items and their materials, measurands and their measuring strategies as well as handling and transit strategies. The selection of the assemblies was conducted defining the following requirements: a) involving assemblies whose x-ray absorption ratios vary from 0.3 to 0.6, b) having items with and without well-defined geometries and low form errors, c) featuring multi-material measurands, d) having assemblies covering different measuring volumes to catch different classes of errors, e) being calibrated using a tactile CMM, f) involving materials with good dimensional stability, g) ease of manufacture and of positioning in a fixture to minimize the reproducibility uncertainty. While some specifications were relatively straightforward to be achieved, others (e.g. trade-off between number of assemblies and number of measurands or x-ray absorption ratios) required several iterations, during which the participants were actively involved. The process resulted in selecting two assemblies: Assembly 1 (see Figure 2a) as the physical item and Assembly 2 (see Figure 2b) as the voxel item.

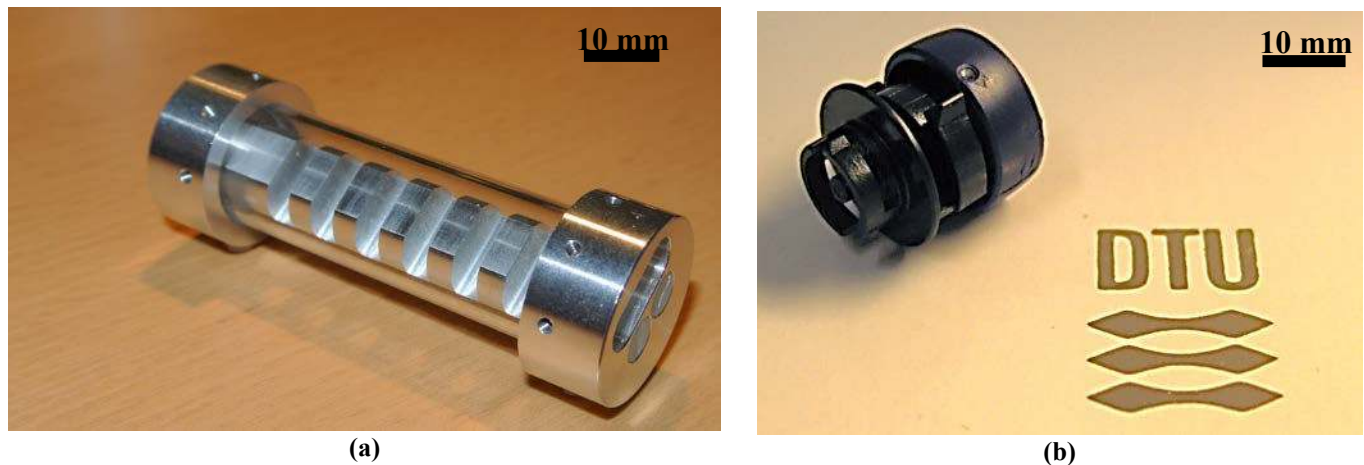


Figure 2: The two items selected in the InteraqCT comparison: (a) Assembly 1 and (b) Assembly 2.

1.1 Assembly 1

Assembly 1 is a multi-material assembly comprising a cylindrical step gauge made out of aluminium and a tube made of glass and two fastening caps. The assembly includes both mono-material measurands such as uni-directional and bidirectional lengths on the gauge (hereafter “gauge measurements”) and multi-material measurands (hereafter “gauge-tube measurements”), defined as the distances between the top of teeth of the gauge and the tube. These measurands can be directly calibrated using a tactile CMM. The cylindrical step gauge is a 56 mm long item with 6 grooves at 3.50 mm steps, produced by milling from a 14 mm diameter extruded rod. Machining enabled a suitable surface finish ($R_a = 0.40 \pm 0.05 \mu\text{m}$ and $R_z = 2.20 \pm 0.05 \mu\text{m}$) to be achieved, as quantified using a stylus instrument on a 5 gauges ($\lambda_s = 2.5 \mu\text{m}$ and $\lambda_c = 0.8 \text{ mm}$, sampling length of 4 mm, and 3 replications per gauge) [4]. An example of surface profile is shown in Figure 4. The glass was purchased as 1m long tubes and afterwards cut in 55-mm-long small tubes in-house. Tubes feature an outer diameter of 17.5 mm and a wall thickness of approximately 1.2 mm which was assumed sufficient to prevent breakage problems caused by thermal expansion and contact pressure. The aluminium caps together with 10 nylon screws complete the assembly as fastening system. 4 screws (M3 x 8 mm) constrain relative displacements between the gauge and the tube, while 6 screws (M2 x 5 mm) constrain the relative rotations. The latter screws are located in such a way as to push the glass against the step gauge, thereby producing a more stable connection over time. Preliminary tests were conducted basis from August to December 2015 on a series of 5 glass tubes and 5 gauges to document the dimensional stability on a monthly. Dimensional measurements were carried out using a tactile CMM described later in connection with the calibration. Variations were estimated within $1.5 \mu\text{m}$ for both tubes and gauges, as shown, for example, in Figure 6. A further investigation was undertaken to document the isotropy of tubes with respect to x-ray penetration. Differences below 4.5 % were observed comparing the extension of the histograms of grey values and two grey value profiles, taken in the centre of the beam (best condition) and in proximity of the detector’s borders (worst condition). The investigation was conducted on a Nikon XT H 225 ST CT scanner (Voltage = 90 KV, Current = 175 μA , magnification = $5.66 \mu\text{m}$, and exposure time = 1000 ms).

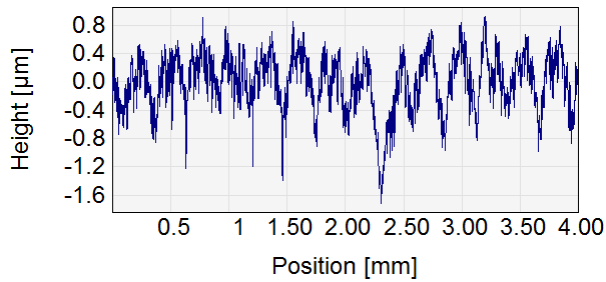


Figure 4: Example of a roughness profiles taken on a step gauge.

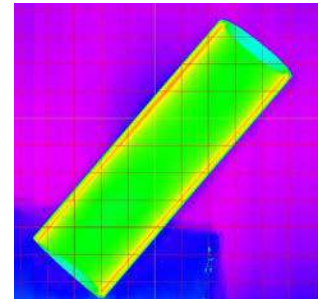


Figure 5: 2D image of a glass tube showing the uniformity of grey values within the zone of interest on the tube (green part).

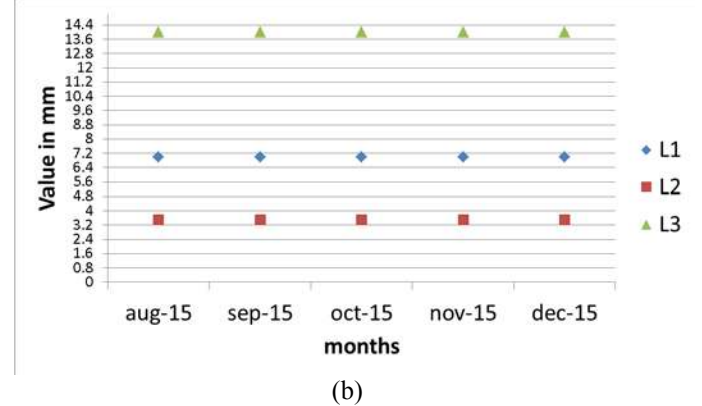
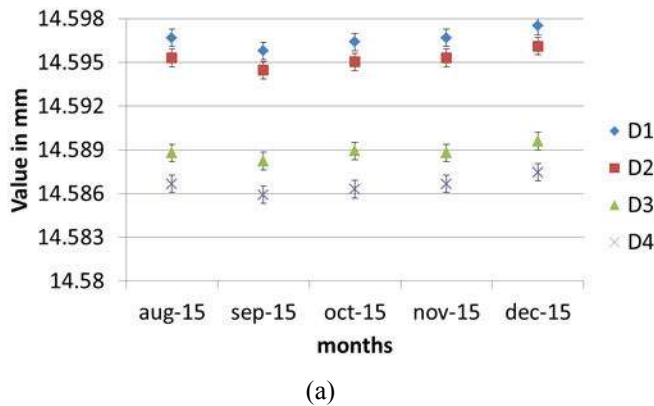


Figure 6: Stability of (a) glass tube no. 1 and (b) step gauge no. 4 over five months.

The measurands selected on Assembly 1 are the following: L1, L2, L3, L4, and T, which are shown in Figure 3 and detailed in Table 1. Participants are offered to perform CT measurement using two strategies:

- a) by own choice: participants are free to select all scanning parameters.
- b) by fast scan: Assembly 1 should be scanned in less than 1 hour, without averaging and replication.

The first strategy enables to extract the best out of CT, as most of the influence factors such as noise, undersampling, ring artefact and pixel delay are the smallest. The second approach attempts to put CT in which it is difficult to mitigate the influence factors. Combining those approaches will provide evidence to inform users, with special reference to fast scans. The latter is a key factor that may affect the successes and failures of CT in industry.

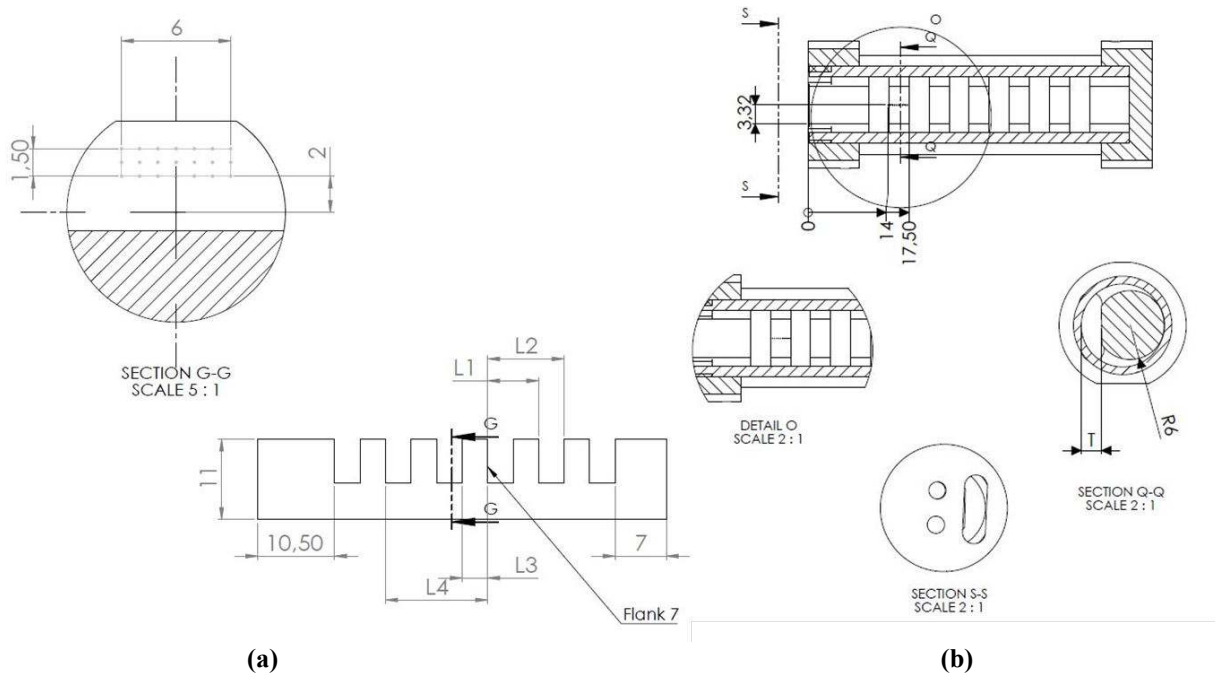


Figure 3: Measurement details for (a) gauge measurements and (b) gauge-tube measurement on Assembly 1.

Identification	Features	Description
L1	Unidirectional length on gauge	Distance between flank 7 and flank 9. The distance is measured using two planes (GG). The position of planes is shown in figure 5.
L2	Bidirectional length on gauge	Distance between flank 7 and flank 10. The distance is measured using two planes (GG). The position of planes is shown in figure 5.
L3	Bidirectional length on gauge	Distance between flank 7 and flank 6. The distance is measured using two planes (GG). The position of planes is shown in figure 5.
L4	Unidirectional length on gauge	Distance between flank 7 and flank 3. The distance is measured using two planes (GG). The position of planes is shown in figure 5.
T	Bidirectional length on gauge-tube	Top distance between the top of the first tooth and the glass tube.

Table 1 Description of measurands of Assembly 1 provided to participants.

1.2 Assembly 2

Assembly 2 is an industrial multi-material assembly kindly provided by Novo Nordisk A/S. The assembly is a two-part component from a commercial insulin injection device from Novo Nordisk A/S (figure 6a). The inner component is made of Polyoxymethylene. The outer component is made of ABS-polycarbonate. Both are produced via injection moulding. Only the outer component of the workpiece is considered because it has the lowest absorption, and therefore is more challenging to scan and post-process. The measurands for Assembly 2 are the following: D1, D2, R2, and C1, as reported in Figure 6b and Table 2. Assembly 2 was scanned by the coordinator for distribution as two CT data sets (see figure 6c) differing in terms of image quality.

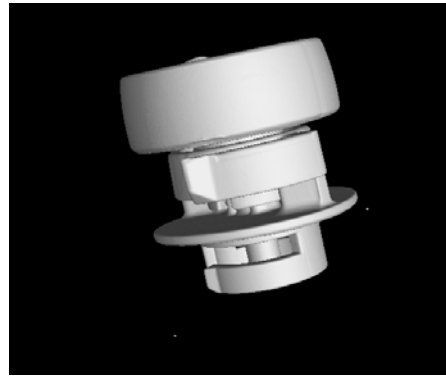
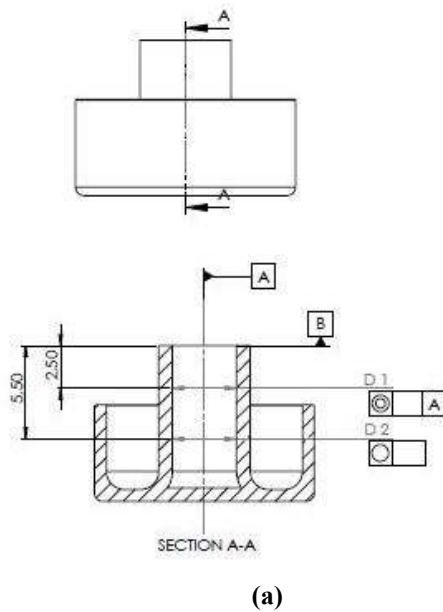


Figure 6: Measurement details for outer part of Assembly 2 and b) 3D volume of Assembly 2.

Identification	Features	Description
D1	Diameter	Internal diameter, least square fitting (GG) D1 – circle is measured at 2,50 mm from datum B.
D2	Diameter	Internal diameter, least square fitting (GG) D2 – circle is measured at 5,50 mm from datum B.
R2	Roundness	Roundness of the internal diameter D2 (LSCI). It is defined 5,50 mm below from datum B.
C1	Concentricity	Concentricity of the internal diameter D1 (LSCI) with respect to datum A.

Table 2 Description of measurands for Assembly 2 provided to participants.

2 Preliminary calibrations

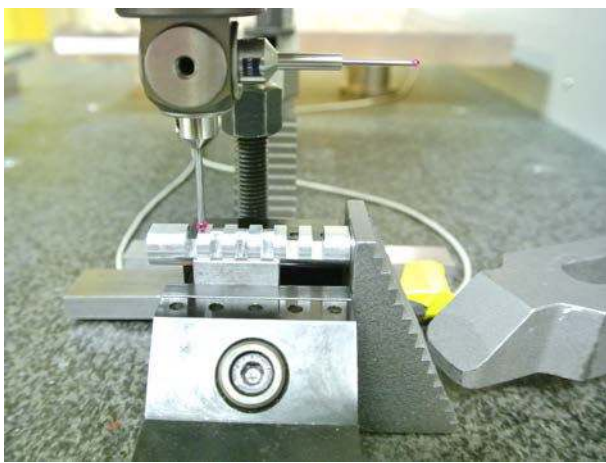
Preliminary cycles of calibrations were carried out on a sample of Assembly 1 and Assembly 2 to document the feasibility of the calibration. Calibrations were conducted on a Zeiss UPMC 850 CARAT at CGM [5]. The CMM is characterized by a volumetric maximum permissible error (MPE) of $0.8+L/600 \mu\text{m}$ (L in mm) and placed in a temperature controlled at $20.0\pm 0.5^\circ\text{C}$. The probe configuration used for Assembly 1 consisted of two probes, one vertical (diameter of $\varnothing 3.0 \text{ mm}$ and stylus length of 40 mm) and one horizontal (diameter of $\varnothing 2.0 \text{ mm}$ and stylus length of 32 mm). For Assembly 2, a 20-mm-long probe with a diameter of $\varnothing 0.8 \text{ mm}$ was selected. No relative compensation of the temperature between two probes was necessary for the probe configuration for Assembly 1 due to the stability of the environment temperature, while compensation for both series of assemblies was automatically performed by the CMM software.

A probing force of 0.01 N was set for gauge measurements while 0.05 N was selected for tube-gauge measurements and for Assembly 2. This difference is necessary to prevent deformations due to the limited mechanical properties of glass and PC-ABS. The probing speed and acceleration were reduced for glass-gauge measurements for the same reason. Traceability was established using two gauge blocks for gauge measurements, and a ring gauge for gauge-tube measurements. The probing

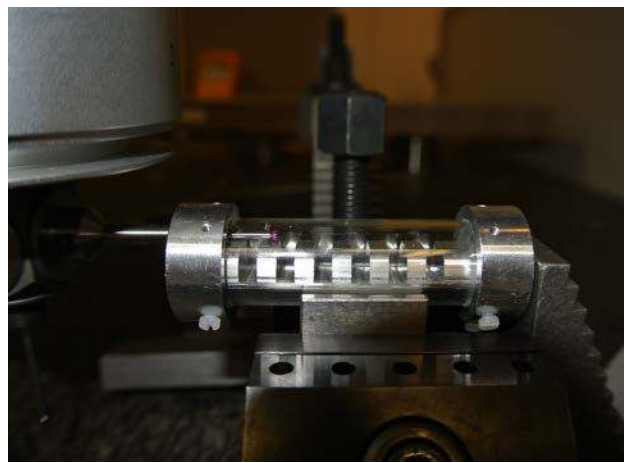
spheres were calibrated prior to calibrating assemblies and subsequently recalibrated at a frequency of every 5 samples measured. The deviations registered were constantly inside the MPE of the CMM.

2.1 Assembly 1: Gauge measurements

The measuring setup is shown in figure 7a. Two circles comprising 15 points each were used for the spatial alignment. A plane of 20 points on the top of the teeth, delimiting the region of the gauge under consideration, was used for the plane alignment. Ultimately, the zero point was set on flank 7 at 2 mm above the cylindrical datum axis. The stability of the alignment was also quantified. Measurements were based on 6 points, distributed on a star-like pattern. No plane fitting was used to quantify the length measurements in order to minimize the extent of form errors (flatness and parallelism) on the flanks. Measurement uncertainties were estimated using the PUMA method [21], and the following uncertainty contributions were considered: 1) reference artefact u_r , 2) repeatability on reference artefact u_{rep} , 3) temperature effects u_e , 4) reproducibility u_p where the parts were repositioned and measured again five times, and 5) variability of workpiece expansion coefficient u_α assuming a range of variability of 10% of the CTE value. Except for the repeatability, the contributions were evaluated using a Type B evaluation. Depending on the item and the measurand, average expanded measurement uncertainties ($k=2$) ranging from 2.5 μm to 3.0 μm were estimated. Errors in flatness of the flanks were found to be no larger than 1.3 μm .



(a)



(b)

Figure 7: Measurement setup for calibration of (a) gauge measurements and (b) gauge-tube measurement using the CMM.

2.2 Assembly 1: Gauge-Tube measurement

The measuring setup is shown in figure 7b. The alignment was performed using a rough alignment and a fine alignment. The first one was used to identify a zero point in X, which was placed on the cap, while the fine alignment was used for measurements. Two circles based on 30 points equally distributed were probed on the tube to define a cylindrical datum and then the spatial alignment. The tube was used as a datum to minimize misalignments and to ensure the position stability throughout calibrations. 7 measurement lengths were measured along an inspection line of 1.5 mm and subsequently averaged. Some issues were encountered during measuring in connection with the stability of the fixture and its effect on the glass stability. Expanded measurement uncertainties ($k=2$) were estimated up to 5 μm .

2.3 Assembly 2

The outer part of Assembly 2 was measured as shown in figure 8 without the necessity of repositioning it. Spatial alignment was based on cylindrical datum using a scanning measuring mode. The zero point was defined as intersection between a plane, laid on the top part, and the axes of spatial alignment, as schematically reported in figure 6. 7 measurement lengths were measured along an inspection line of 1.5 mm and subsequently averaged to qualify the multi-material measurand. The measurement uncertainty was quantified similarly to Assembly 1. Expanded measurement uncertainties ($k=2$) ranging from 3.2 μm to 3.9 μm were estimated depending on the measurands.

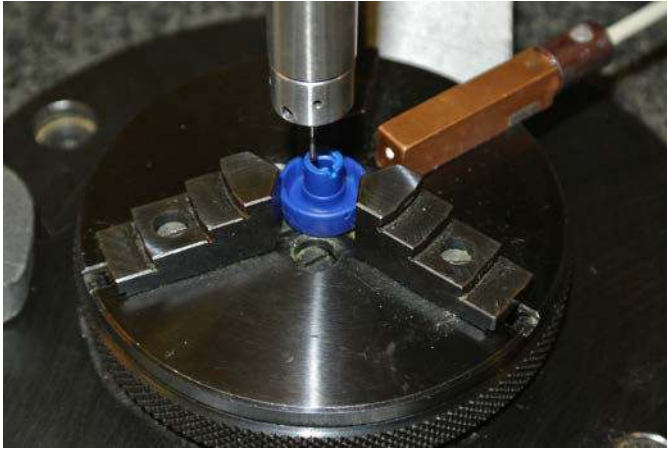


Figure 8: Measurement setup for calibration of the outer part of Assembly 2.

3 Conclusions

This paper presented the two assemblies selected for the “InteraqCT comparison on assemblies” involving 22 participants in Europe and Asia. Assembly 1 is a physical item designed and manufactured at DTU, while Assembly 2 is an industrial assembly, provided by Novo Nordisk A/S. The dimensional stability of the materials comprising Assembly 1 was successfully documented. A series of explorative calibrations were carried out on both assemblies using a tactile CMM that provided a documentation on the reliability of the measuring strategies and of the measuring setups selected. Measuring uncertainties were quantified to be no larger than to 5 μm depending on assemblies and measurands.

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under REA grant agreement no. 607817 INTERAQCT. The valuable contributions of the following persons are gratefully acknowledged: Adam Thompson (University of Nottingham), Angela Cantatore (Metrologic ApS), Bieke Smenunx (Nikon Metrology Europe NV), Gemma Fardell (Nikon X-tek), Henning Stoschus (Werth), Jan Frank Pedersen (DTU), Jan Lassen Andreasen (Novo Nordisk A/S) Kim Kiekens (Group T – Leuven University College, KU Leuven Association), Kristof Peeters (Nikon Metrology Europe NV), Lars Brøndbjerg (3D-CT A/S), Lorenzo Carli (Novo Nordisk), Markus Bartscher (PTB), Mary Kathryn Thompson (DTU), Michael McCarthy (NPL), Paras Shah (University of Huddersfield), Paul Bills (University of Huddersfield), Peder Pedersen (Teknologisk Institute), Per Wittendorff (Metrologic ApS), Rene` Sobiecki (DTU), Robert Schmitt (RWTH Aachen), Simone Carmignato (University of Padua), Skov Mortensen (3D-CT A/S), Wenchao Cao (Nikon X-tek), Wim Dewulf (Group T – Leuven University College, KU Leuven Association).

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